

Knowledge Based Functions for Routine Use at a German University Hospital Setting: The Issue of Fine Tuning

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In this paper we present the introduction of knowledge based functions into clinical routine at Gießen University Hospital. For this purpose a therapy planning module at the medical intensive care unit has been extensively redesigned in order to support the structured documentation of drug prescriptions. After introduction of this new HIS component in January 1996 research has been initiated to establish a basic drug therapy knowledge base. The main components of a knowledge based system have been fully incorporated into the hospital information system WING and are in routine use since December 1996.

During a pre-production phase warnings of reminder functions were logged and reviewed by an interdisciplinary team in order to adapt the system to the actual clinical environment. The paper describes experiences during this fine tuning and adaptation process which was necessary to bring a small set of knowledge modules into clinical routine.

INTRODUCTION

Artificial Intelligence and expert systems have invaded early in Medicine. Mycin was one example and continuous development efforts lead to highstanding systems such as Iliad or QMR [1,2,3,4,5]. Nevertheless, most of those systems have not found their way into clinical routine use [6,7,8]. Standalone diagnostic expert systems are propagated and successfully employed in the area of computer based education and learning [8,9]. Small areas of medicine have been well covered with routinely employed small expert systems [10,11]. In those hospitals where knowledge based functions (KBF) have been directly integrated into hospital information systems, this approach has proven to be successful [12,13,14]. Furthermore, formal evaluation studies exist, which have shown, that such functions can improve process quality and reduce costs [14,15,16]. These latter successful approaches share the common idea, that suggestions and reminders are generated on the

base of clinical data already available in the system without forcing the user into a time consuming and tedious dialog about relevant findings.

At Gießen University hospital a self developed hospital information system called WING has been started in 1989 [17] and is under continuous and evolutionary development [18]. Having a certain amount of clinical data such as lab results, diagnoses, coded procedures or doctors letters readily available in the system, we joined a German research project [19] in 1993 with the aim to implement knowledge based functions for drug prescription. As in the HELP and RMRS approaches, it was our goal to establish the knowledge based functions on top of already existing patient data, not requiring any additional user dialog.

METHODS

Background

Gießen University Hospital is a 1,350 beds hospital with about 35,000 inpatients and 320,000 outpatients yearly. The campus area is spread over an area of about 1.5 km².

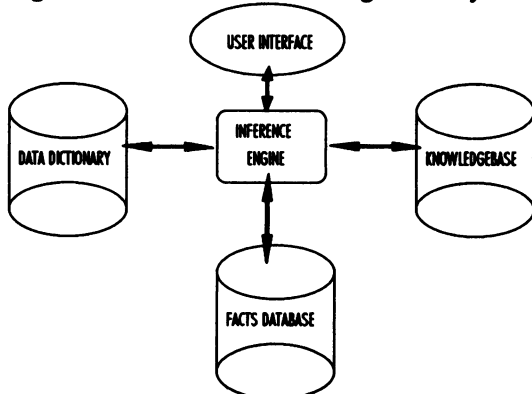
The Gießen HIS WING is based upon a four processor TANDEM Himalaya mainframe. Using the Tandem proprietary PATHMAKER transaction monitor, clinical applications have been developed on top of a relational database (Tandem NonStop SQL) in strict client server fashion. A modular set of services, written in C or COBOL and grouped into servers accesses the database to insert, retrieve, or update stored information. Frontend applications can either reside on terminal emulation programmed in a COBOL dialect, or they can be located on Macintosh-PC-clients with a graphical user frontend developed in C language. Frontend and backend communicate with each other via messaging structures. The system can be accessed from more than 1,000 PCs and Macintosh workstations which are implemented throughout the whole hospital (e.g. nursing stations, outpatient clinics, physician offices, operating theatres and administrative offices).

Implementation of Knowledge Based Functions

Our approach for the design of knowledge based functions was to fully incorporate the standard architecture of a knowledge based system (see figure 1) into our HIS environment [20].

As a first step a comprehensive data dictionary structure has been designed, which maps the descriptive data of the pharmacy application into a controlled vocabulary [21]. The second step consisted in design adaptations of the clinical database to serve as a facts database for the KBF. In the third step extensive reprogramming was applied to the user interface of the preexisting purely freetext-based therapy planning module. The fourth step consisted in building the knowledge base in a modular fashion, suitable for the latter use of ARDEN-syntax modules [22]. In the fifth step a first and rudimentary version of an event handler was build, which in the future shall evolve to a clinical event monitor [23].

Figure 1: Structure of a knowledge based system



THE APPLICATION IN USE

The drug prescription module is employed on the medical intensive care unit of the university hospital, one of the few places within our hospital where bedside computing facilities are available. This seems essential to avoid repeated data caption (see also [12], pp 147-151). Figure 2 shows the redesigned alphanumeric user interface for medication entry. The header contains patient demographic data. On the right a ward specific hitlist of frequently prescribed drugs is generated on the basis of the data dictionary. On the left the actual therapy plan of the selected patient is compiled. As a default, the actual therapy plan is always displayed, so that it can be easily modified. Modifications are performed in the single line at the left bottom (behind F14) for one drug at a time. One

drug prescription is described by the attributes dosage, schedule, route, duration and a freetext comment. The user interface design evolved on the request of the ward staff who wanted to maintain the freedom of the earlier used text editor facility to write clinical information such as „elevate body 45 degree“ beneath the actual therapy scheme.

Figure 2: Redesigned medication entry screen

Pg MEDS IV-Verordnung		Termin TRMD84		24.08.95 17:55:12	
Stat: 9411886 Notaufnahme-Station		Med. Kl. Medizinische Klinik		Tel: 3859	
Name: 2002		EDUARD		P: 309637	
Aufnahme: 08-07-1995 14:00		Erläuterung: 19-02-1979		A: 30168836	
		BfK: STAT			

IV-Medikation				kur 24.08.1995		= Auswahlliste S 1/4 =	
	n	Dosis	Medikament	Tag			
F1	2 x	.50	Zaric			SF 1 ACC Amp	
F2	3 x	2.00	ACC Amp			SF 2 Actosol mg	
F3	1 x	.50	Lentacor Amp			SF 3 Antra Amp	
F4	6 x	20.00	Leuk mg			SF 4 Asplad Amp	
F5	1 x	2.00	Staphylex g	16 #		SF 5 Augmentin mg	
F6	1 x	.20	Dilucan g	10		SF 6 Azactam mg	
F7	x		Decortin H mg	14 #		SF 7 Baclofen Amp	
						SF 8 Biotec mg	
						SF 9 Bromoc Amp	
						SF 10 Calceon mg	
						SF 11 Carbid g	
						SF 12 Ciprobay g	
						SF 13 Clont mg	
						SF 14 Combactam g	
						SF 15 Decortin H mg	

Seite 1/3		F14 3 x 1.00 Antra Amp			
Kommentar:		8 Uhr, 12 Uhr, 16 Uhr geben			
F12-epibchem		F13-duchen		F14-akt-Med-beschen	
F15-Medlern-I		F16-Medlern-II		F17-Infusion	
Daten vom 23.08.1995 12:46 werden angezeigt					

The program is then used to print a paper drug chart once a day (figure 3). Within 15 months of routine use of the new drug prescription module some 65.000 prescriptions for 500 patients have been recorded.

During this time the event handler mentioned above and a first small, but modular knowledge base, consisting of four monitoring modules have been implemented.

Today, computer generated reminders are printed at the bottom of the therapy plan. The monitoring modules are in routine use since about 3 months. One of the existing four reminder modules warns in case of prolonged antibiotic administration. Elevated creatinine levels in combination with renally excreted drugs are flagged by another module. Warnings occur also when inappropriate aminoglycoside blood levels are detected and aminoglycosides are administered. The application of drugs containing potassium prompts a warning, if high blood potassium levels are found.

FINE TUNING OF THE KBF

Before we put our monitoring modules into routine use, all generated alerts have been logged into a database for a period of 6 months and have been exemplarily discussed with the physicians. In this period we registered on average 500 alerts per month which seemed to be much too high. Therefore for a short time period the alerts have

also been printed on the ward and a simultaneous questionnaire study with the responsible physicians was performed. This questionnaire contained 6 questions and had to be filled for each printed warning. The clinician was asked if the reminder function had worked reliably, and if the printed information was sufficient to assess the warning. We asked if the mode of communication (printout

with the therapy plan) had been suitable and if the warning had been appropriate considering the clinical appearance of the patient. Furtheron we wanted to know, if the reminder had delivered information which had not yet been noted by the physician and if a change in therapy had occurred on base of the reminder.

Figure 3: Printed therapy plan with 2 alerts

MEDIZINISCHE-KLINIK - INTENSIVSTATION					
THERAPIEPLAN gedruckt am: 08.07.1996 11:20			Seite: 01		
Name: BAxxxx, FExxxx			Aktualisiert: 07-07-1996 15:19		
Lv.	Tag	oral	Infusion		
3 x 4	Baypen g (2)	2 x 1 Tyklid Tabl	2 x 1 5000	Heparin IE	
3 x 1	Combectam g (2)		2 x 100	Dopamin mg	
4 x 2	Bromuc Amp		2 x 1	Lidocain g	
2 x 1	Zantic Amp		-	Insulin IE/h Perf.	
1 x 100	Aspirin mg		-	Fentanyl / Dormicum	
6 x 40	Lasix mg a.A.		2 x 500	Aminoplasmal 10% ml	
			+ 2 x 20	NaPO4 mVal	
			2 x 250	Lipovenoes 20% ml	
			+ 1 x 1	Cernevit Amp	
			2 x 500	Glucose 40% ml	
			+ 2 x 30	Insulin IE	
			+ 2 x 60	KCL mVal	
Kreatinin ist hoch : am 7. 7.1996 7:00 Wert 2.200 mg/dl					
→ Bei Patient mit patid 51xxxx wurde aber			3 x 1.00 Combectam g	angesezt	
Kalium ist hoch : am 7. 7.1996 13:30 Wert 5.710 mg/dl					
→ Bei Patient mit patid 51xxxx wurde aber			2 x 60.00 KCL mVal	angesezt	

The results of this study based on 32 alerts can be seen in table 1.

Table 1: questionnaire on 32 alerts

	yes	no	don't know
reliability ok	27	3	2
enough information	23	6	1
communic. mode ok	27	5	
clinical correct	5	27	
new information	1	31	
therapy change		32	

The reliability of the knowledge based functions was considered fairly high (84% positive answers) and our doctors were content with the communication via the printed therapy plan. Most alerts (72%) contained enough information for correct judgement.

In the clinical context of patient treatment however only 5 alerts (15%) have been considered appropriate, the remaining alerts did not take care of clinical facts which were known to the physician, but not yet available in the WING patient database. Only one alert yielded information which at the time of warning was not known to the physician.

No therapy change has been prompted by any of the observed 32 warnings.

We took the results of the questionnaire as an incentive for an extensive fine tuning of all knowledge based functions. Not only have alarm limits been readjusted, but the logic of the functions has been changed to accomodate additional clinical facts, if anyhow available. This shall be illustrated by the following example. When we started to implement functions, we thought of monitoring the level of aminoglycosides in blood. Toxic levels of these antibiotics can cause severe damage to kidneys and the ear. Therefore aminoglycoside levels are measured routinely twice a week. A monitoring function was implemented which scanned the most recent lab result and warned in case of toxic levels. However, since samples are taken before and after administration of the drug, often warnings were issued when high peak levels occurred shortly after administration. The monitoring function was redesigned to consider also a small bit of unstructured textual information within the laboratory results database, which allows in most cases to distinguish between peak and minimum („through“) levels. Today warnings are

issued if a value is considered to be a through value and is too high or if a value is considered to be a peak level and is not in the therapeutic range. No warning is given if the lab result cannot be attributed with a peak or through level.

As a result of this and similar other activities the alert frequency has been brought down to about one fifth of it's old value. Now approximately 3 warnings are generated on average each day which seems to be just the maximum amount tolerable for the ward staff.

DISCUSSION

We described the introduction of a small set of knowledge based functions into clinical routine on a busy medical intensive care unit. During this activity we experienced, in agreement with Evans [24], that for each knowledge module extensive testing and fine tuning is required. As also reported by Pryor and Hripcsak [25], taking standard textbook knowledge or knowledge based functions of other clinical sites directly into the own place proved not to be possible. Apart from registering the warnings in a database first, we used a rather informal questionnaire study for the fine tuning process with encouraging results. It is noteworthy to mention that the discussion with the medical staff on the ward was much more effective once the monitoring functions were in action and the questionnaire was distributed. Only then the medical staff became really aware of our clinical intention and started to cooperate in a productive manner.

For the future extension and further finetuning steps an important issue which needs to be considered is the maximum daily frequency of alerts which doctors will tolerate. In our case, up to

now 3 alerts a day on a 9 bed intensive care unit seem to be just acceptable. This implies, that if more monitoring functions are to be implemented, the currently active ones have to be tuned to an even lower degree of warning activity. We gain the impression, that monitoring functions are most effective if they are triggered extremely seldom instead of delivering too many false positive alerts. This means that effective monitoring functions have to be restricted to the most dangerous and life threatening situations, taking the chance that they fire only once a year. By no means should one attempt to fill all available textbook knowledge into monitoring functions as this will result in far too many warnings.

The depicted questionnaire was not intended for formal evaluation of the KBF. Such evaluation of knowledge based functions is helpful to show their clinical impact. It can however be discussed how and when this should be done [26]. In some cases it might better pay off to improve the current system first than to manifest a steady state, freezing all programming efforts to allow a multiphase evaluation.

In Gießen we decided to continue to improve and add more KBF first before making formal evaluation efforts. Once we have gained more experience and managed to widen the spectrum of KBF to other areas of our university hospital, a formal evaluation of clinical impact will be performed.

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REFERENCES

- [1] Buchanan B.G. and Shortliffe, E.H., Rule-Based Expert Systems - The MYCIN Experiments of the Stanford Heuristic Programming Project. Addison Wesley, Reading, Massachusetts (1984).
- [2] Warner H. R., Computer assisted Medical Decision Making. Academic Press, New York (1979).
- [3] Hayes-Roth R., *et al.*, Building Expert Systems. Addison Wesley, London (1983).
- [4] Cundick R, *et al.*, Iliad as a Patient Case Simulator to Teach Medical Problem Solving. In: Proceedings 13th SCAMC, IEEE Computer Society Press, Los Alamitos, California (1989).
- [5] Sumner II W. and Shultz E. K., Expert Systems and Expert Behavior. *J. Med. Sys.* 5 (1992) 183-191.
- [6] Shortliffe E.H. Knowledge-based Systems in Medicine. In: Adlassnig K.-P., *et al.* (eds) MIE '91 Proceedings Vienna, Springer Berlin (1991) 5-9.
- [7] Wong E.T. *et al.*, Interfacing a stand-Alone Diagnostic Expert System with a Hospital Information System. *Comp. Biomed. Res.* 27 (1994) 1116-129.

- [8] Bergeron B., Iliad: A diagnostic Consultant and Patient Simulator. *MD Comput.* 1 (1991) 46-53.
- [9] Turner C. W., *et al.*, The Effects of Iliad on Medical Student Problem Solving. In: Proceedings 15th SCAMC, IEEE Computer Society Press, (1992) 68-77.
- [10] Aikins J.S., *et al.*, PUFF: An Expert System for Interpretation of Pulmonary Function Data. *Comp. Biomed. Res.* 16 (1983) 199-208.
- [11] Adlassnig K.-P. and Horak W., Development and retrospective evaluation of HEPAXPERT-I: a routinely used expert system for interpretive analysis of hepatitis A and B serologic findings. *Artificial Intelligence in Medicine* 7 (1995) 1-24.
- [12] Kuperman G.J. *et al.*, HELP: A Dynamic Hospital Information System. Springer New York (1991).
- [13] McDonald C.J., *et al.*, The Regenstrief Medical Record System: 20 Years of Experience in Hospitals, Clinics, and Neighborhood Health Centers. *MD Comput.* 4 (1992) 206-217.
- [14] Rind D.M. *et al.*, The Effect of Computer-Based Reminders on the Management of Hospitalized Patients with Worsening Renal Functions. In: Proceedings 15th SCAMC, IEEE Computer Society Press, (1991) 28-32.
- [15] Prokosch H.-U. and McDonald C. The Effect of Computer Reminders on the Quality of Care and Resource Use. In: Prokosch, H.U. and Dudeck, J. (Eds.) Hospital Information Systems: Design and Development Characteristics; Impact and Future Architecture. Elsevier Science, Amsterdam (1995) 221-239.
- [16] Evans R.S. *et al.* Evaluating the Impact of Computer-based Drug Monitoring on the Quality and Cost of Drug Therapy. In: Prokosch, H.U. and Dudeck, J. (Eds.) Hospital Information Systems: Design and Development Characteristics; Impact and Future Architecture. Elsevier Science, Amsterdam (1995) 201-220.
- [17] Prokosch H.-U. *et al.*, WING - Entering a New Phase of Electronic Data Processing at the Gießen University Hospital, *Meth. Inform. Med.* 30 (1991) 289-298.
- [18] Michel A., Migration Steps from a mainframe based HIS approach to an open HIS environment. In: Prokosch, H.U. and Dudeck, J. (Eds.) Hospital Information Systems: Design and Development Characteristics; Impact and Future Architecture. Elsevier Science, Amsterdam (1995) 267-286.
- [19] Eimeren, W van: MEDWIS. *Informatik, Biometrie und Epidemiologie in Medizin und Biologie*, 26 1 (1995) 67-77.
- [20] Bürkle, T. *et al.*, Steps towards Integration of Knowledge Based Functions into a Hospital Information System. In: Brender J. *et al.* (eds) MIE '96 Proceedings Copenhagen, IOS Press Amsterdam (1996) 286-290.
- [21] Prokosch H.U. *et al.*, MDD-GIPHARM: Design and Realization of a Medical Data Dictionary for Decision Support Systems in Drug Therapy. *Informatik, Biometrie und Epidemiologie in Medizin und Biologie*, 26 3 (1995) 250-261.
- [22] Hripcsak G. *et al.*, Rationale for the Arden Syntax. *Computers and Biomedical Research*, 27 (1996) 194-221.
- [23] Hripcsak G. *et al.*, Design of a Clinical Event Monitor *Computers and Biomedical Research*, 29 (1996) 194-221.
- [24] Evans R.S. The HELP System: A Review of Clinical Applications in Infectious Diseases and Antibiotic Use. *MD Comput.* 5 (1991) 282-315.
- [25] Pryor T.A. and Hripcsak G., Sharing MLM's: An Experiment between Columbia-Presbyterian and LDS Hospital. In: Proceedings 17th SCAMC, IEEE Computer Society Press, (1994) 399-403.
- [26] Shortliffe E.H. The adolescence of AI in Medicine: Will the field become of age in the '90s? *Artificial Intelligence in Medicine* 5 (1993) 93-106.